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Extrasolar Planets: from Individual Detections to Statistical Properties

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Abstract. Ten new planet candidates are announced as part of our ELODIE and CORALIE planet search programs in both hemispheres. Most of them present properties common to the known extrasolar planets. One candidate (HD 190360 A) shares similarities with our own Jupiter (circular, very long period orbit). The global statistical properties of the orbital element distributions are discussed. Emerging features are pointed out, like the lack of massive planets on short period orbits and the appearance of a *period valley* between ~ 30 and 100 days for the lighter planets, bringing strong observational constraints for the migration scenario. Finally, detection *black sheep* are discussed as well as more complex candidates presently put into questions.

1. Introduction

This meeting has shown a blossom of new extrasolar planet candidates (≥ 20) from various large radial velocity (RV) surveys of solar type stars, bringing the total number of detected extrasolar planets to about 100. The programs involving our Geneva team have contributed 10 new candidates, detected with the ELODIE and CORALIE spectrographs. They will be briefly described in the next section.

The enlargement of the known extrasolar planet list appeals for a reexamination of the statistical properties of the derived orbital elements and stellar host characteristics, in search of constraints for the different planet formation and evolution scenarios. On the one hand, often pointed out features like the *brown dwarf desert* in the mass distribution or the metallicity enhancement of stars with planets are confirmed by the updated distributions. On the other hand, new interesting properties are starting to emerge. “Light” and “massive” planets present different behaviors, especially related to their period distributions (Udry et al. 2002a; Zucker & Mazeh 2002). A *period valley* between ~ 30 and 100 days is now also clearly emerging in the period distribution of the lighter planets bringing new implications for the migration scenario.

The relevance of the features pointed out from the statistical distributions relates on the trust we can put in the detected candidates and on our ability to remove *black sheep* from the sample. Part of this contribution will thus be dedicated to review examples of potential false planetary detections. Two known planetary candidates (HD 83443 c and HD 192263) put into questions by new RV or photometric measurements will be discussed as well.

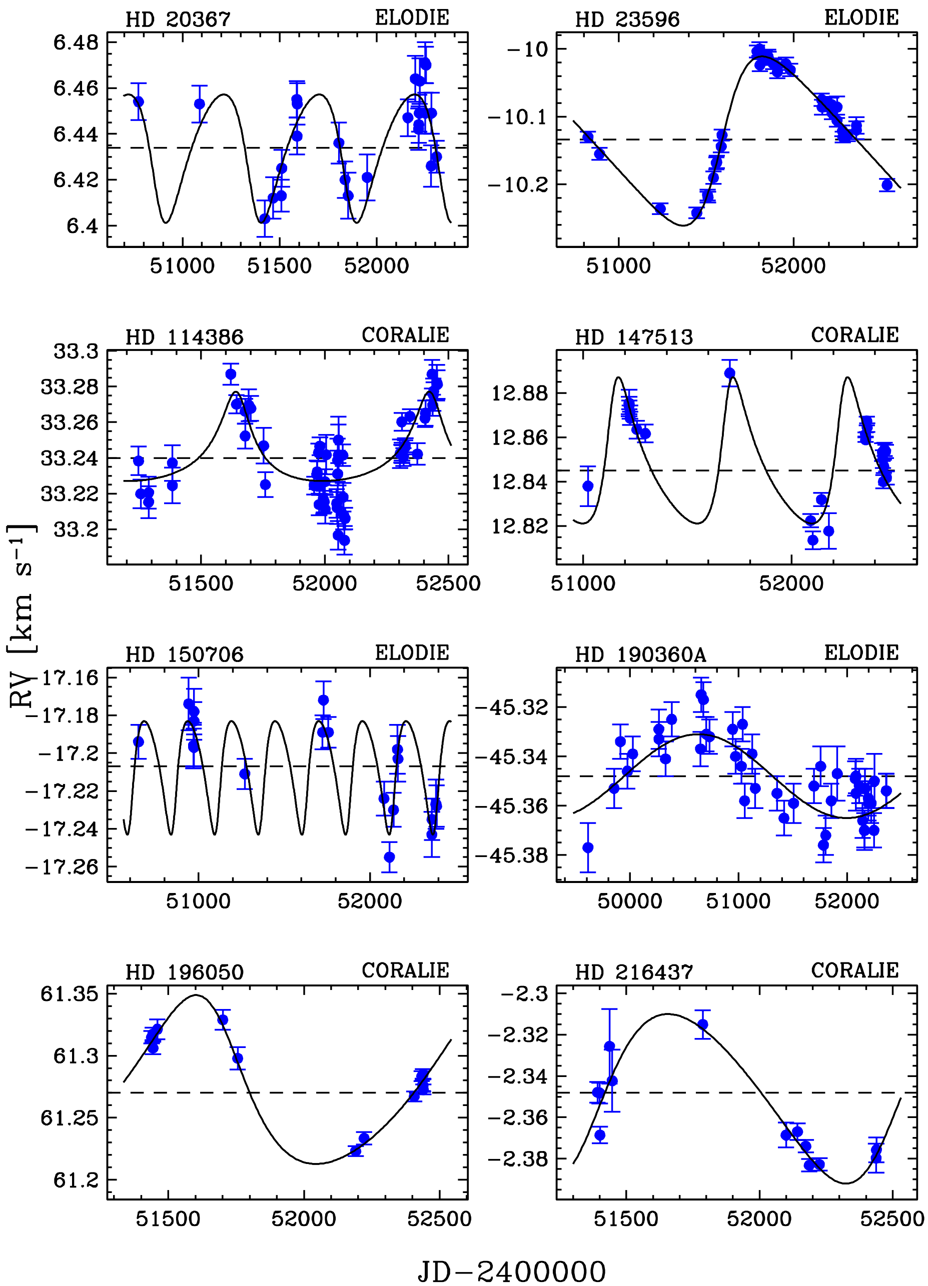

Figure 1. CORALIE and ELODIE radial velocity measurements superimposed to the best Keplerian solutions for 8 of our candidates

Table 1. Main orbital parameters and inferred planetary properties

HD	P [days]	e	K [ms^{-1}]	$m_2 \sin i$ [$\mathrm{M_{Jup}}$]	a [AU]	(O-C) [ms^{-1}]	Instr	Ref
20367	500 ± 6	0.23	27	1.07	1.25	8.6	Elodie	1
23596	1558 ± 32	0.31	125	7.2	2.72	8.2	Elodie	1
33636[b]	3030 ± 1815	0.56	171	10	4.10	16.3	Elodie	1,2
150706	264.9 ± 5.8	0.38	33	1.0	0.80	6.8	Elodie	0
190360A	2614 ± 118	0	17.5	1.15	3.65	9.1	Elodie[a]	0
37124b	153.3 ± 0.4	0.15	29	0.8	0.55		Keck	4
37124c[b]	1947.4 ± 30	0.77	33	1.2	2.95	13.6	Elo+Cor	3,5
114386	781.6 ± 21.1	0.49	25	1.0	1.6	11.4	Coralie	0
147513	549.9 ± 8	0.40	33	1.0	1.26	3.8	Coralie	0
196050[b]	1098 ± 69	0.22	68	3.35	2.08	4.8	Coralie	0,6
216437[b]	1119 ± 60	0.17	41	2.05	2.11	4.5	Coralie	0,6

[a] Compatible with AFOE data, [b] Independent announcement by other groups
Ref: 0: this contribution, 1: Perrier et al. (2002), 2: Vogt et al. (2002), 3: Butler et al. (2002a), 4: Vogt et al. (2000) 5: Udry et al. in prep, 6: Jones et al. (2002)

2. Ten New ELODIE-CORALIE Detections

The ELODIE and CORALIE spectrographs, installed on the 1.93-m telescope at the Haute-Provence Observatory (France) and on the 1.2-m Euler Swiss telescope at La Silla (ESO-Chile), are twin echelle spectrographs, especially designed for high-precision RV measurements using the simultaneous thorium technique (Baranne et al. 1996). The northern ELODIE survey monitors a magnitude-limited sample of ~ 350 F-K close-by dwarfs (Perrier et al. 2002). With a precision improved now to $\sim 6\,\mathrm{ms}^{-1}$, this survey has contributed to the detection of 18 planetary candidates with $m_2 \sin i \leq 10\,\mathrm{M_{Jup}}$. In the southern hemisphere, the CORALIE program follows a volume-limited sample of ~ 1650 F8 to M0 dwarf stars of the solar vicinity (Queloz et al. 2000; Udry et al. 2000) with a precision better than $3\,\mathrm{ms}^{-1}$ (Queloz et al. 2001a). This fruitful survey has revealed 29 extrasolar planets with $m_2 \sin i \leq 10\,\mathrm{M_{Jup}}$ since its launch in June 1998. It has to be noted here that, because of the small size of the telescopes, the precisions achieved on our target stars are mainly photon noise limited.

Table 1 provides the main orbital characteristics of the new planetary candidates detected with ELODIE and CORALIE. The corresponding RV measurements and best Keplerian orbital solutions are displayed in Figures 1 and 2. Most of the candidates share common properties with the known extrasolar planet sample. They have typical jovian planet masses between 0.8 and $3.3\,\mathrm{M_{Jup}}$ except for 2 more massive ones at 7 and $10\,\mathrm{M_{Jup}}$. They are mostly eccentric with long periods ($101\,\mathrm{d} \leq P \leq 2614\,\mathrm{d}$). A few interesting cases are further described below.

A Jupiter analog around HD 190360 A: The star belongs to the first set of targets followed with ELODIE since 1994. The 2600-d period is now fully covered unveiling a jovian planet on a quasi-circular orbit. RV data from AFOE (Korzennik, private communication) are compatible with the derived Keplerian solution. The long period and the almost zero eccentricity make the planet very similar to Jupiter. As the star is close to the sun (parallax $= 62.92 \pm 0.62$ mas),

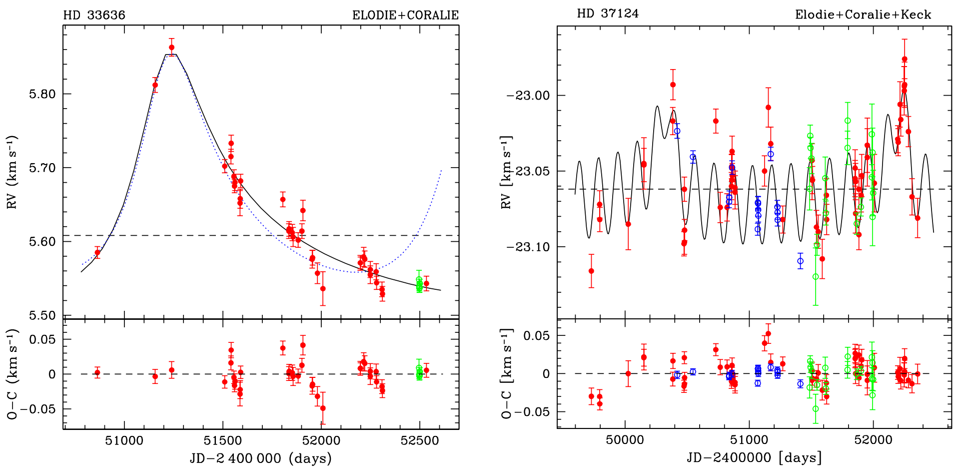

Figure 2. *Left:* ELODIE observations superimposed on our best Keplerian orbit for HD 33636. The shorter period solution derived by Vogt et al. (2002) is also displayed for comparison. *Right:* Two planet solution for HD 37124, simultaneously derived from our ELODIE+CORALIE data and Keck observations from Vogt et al. (2000)

$a_1 \sin i = 0.45$ mas on the sky. This system represents thus an easy target for the future interferometric astrometric facilities (VLTI, SIM).

HD 33636: The massive planet ($m_2 \sin i = 10\,\mathrm{M_{Jup}}$) around HD 33636 moves on a very long period, fairly eccentric orbit. Such objects are very important to understand the planet–brown dwarf transition domain (Udry et al. 2002a). Although we were carefully watching the RV variations of the star since the beginning of the ELODIE program, the minimum of the curve is still hardly covered and the period is thus badly constrained. The planet has been recently, independently announced by Vogt et al. (2002) who quote a much shorter period with also a similarly large relative uncertainty (50%). Both orbits are shown in Figure 2 (left). Recent ELODIE and CORALIE measurements are now ruling out the too short period proposed by Vogt et al.

A two planet system around HD 37124: The first planet orbiting HD 37124 was announced by Vogt et al. (2000) with an observed drift of the systemic velocity indicating the presence of an additional companion in the system. The star was part of the original ELODIE sample and we were also carefully following its RV variations. A second planet, long period, orbit is now fully covered. The simultaneous two planet Keplerian solution is shown in Figure 2 (right) with the ELODIE and CORALIE RVs and the Keck data from Vogt et al. An independent solution is proposed by Butler et al. (2002a).

3. Statistical Properties of Extrasolar Planets

The number of detected extrasolar planets reaching 100, a statistically significant sample is now available to derive meaningful distributions of planetary characteristics and thus try to point out useful constraints for planet-building models. Known properties are confirmed but new features are also emerging. Also, see Marcy et al. (2003) for an independent discussion of orbital statistics.

Stellar metallicity. Precise spectroscopic studies revealed that stars with planets are particularly metal rich when compared with "single" field stars (Gonzalez 1997, 1998; Santos et al. 2001a,b). Furthermore, Santos et al. have shown that the planet frequency is a strong function of [Fe/H] and that the metallicity has a probable primordial origin. The metal-rich nature of star hosting planets is fully confirmed by homogeneous studies of the most recent detections (Santos et al. 2002a; Fischer and Valenti 2003). It tells us that metallicity plays a key role in the formation of giant planets. In particular, from the *metallicity – planetary mass* diagram (Figure 3, upper left), there seems to be a need of a high metal content to form massive planets (Udry et al. 2002a; Santos et al. 2002a).

The planetary mass function. The observed gap in the mass distribution between giant planets and stellar secondaries is often presented as an indication of the existence of two distinct companion populations for solar type stars (e.g., Zucker & Mazeh 2001; Jorissen et al. 2001). The bimodal shape of the mass distribution as well as its rise towards the *harder-to-detect* lower mass planets are confirmed by the new planetary detections. It is however not clear how this bimodal shape changes for longer period planets, as the largest observed mass of planetary companions is increasing with period (Udry et al. 2002b).

The period-mass distribution. In a recent discussion of the statistical properties of massive planets versus lighter ones (Udry et al. 2002a), we emphasized a lack of massive planets on short period orbits. This was also simultaneously pointed out by Zucker & Mazeh (2002, 2003) who also verified its statistical significance and interestingly examined the possible influence of binarity on the planetary mass-period relation. With the enlarged candidate sample, this effect becomes even clearer (Figure 3, right). Removing the binaries, a complete void is observed in the diagram for masses larger than $\sim 2\,\mathrm{M_{Jup}}$ and periods smaller than ~ 100 days. The only remaining point is HD 168443 b, member of a possible multi brown dwarf system (Marcy et al. 2001; Udry et al. 2002a). See also Eggenberger et al. (2003) for a more complete discussion.

In the context of the migration scenario, two types of explanations can be proposed to explain the lack of massive planets on short period orbits: i) migration is less effective for massive planets, they stay farther out than lighter ones (Trilling et al. 2002; Nelson et al. 2002) or ii) when the planet reaches the central regions, some process related to planet-star interactions induces mass transfer from the planet to the star - decreasing the mass of the former (Trilling et al. 1998) - or leads massive planets to fall into the central star (Pätzold & Rauer 2002). These approaches are discussed in more detail in Udry et al. (2002b) in view of the observational results.

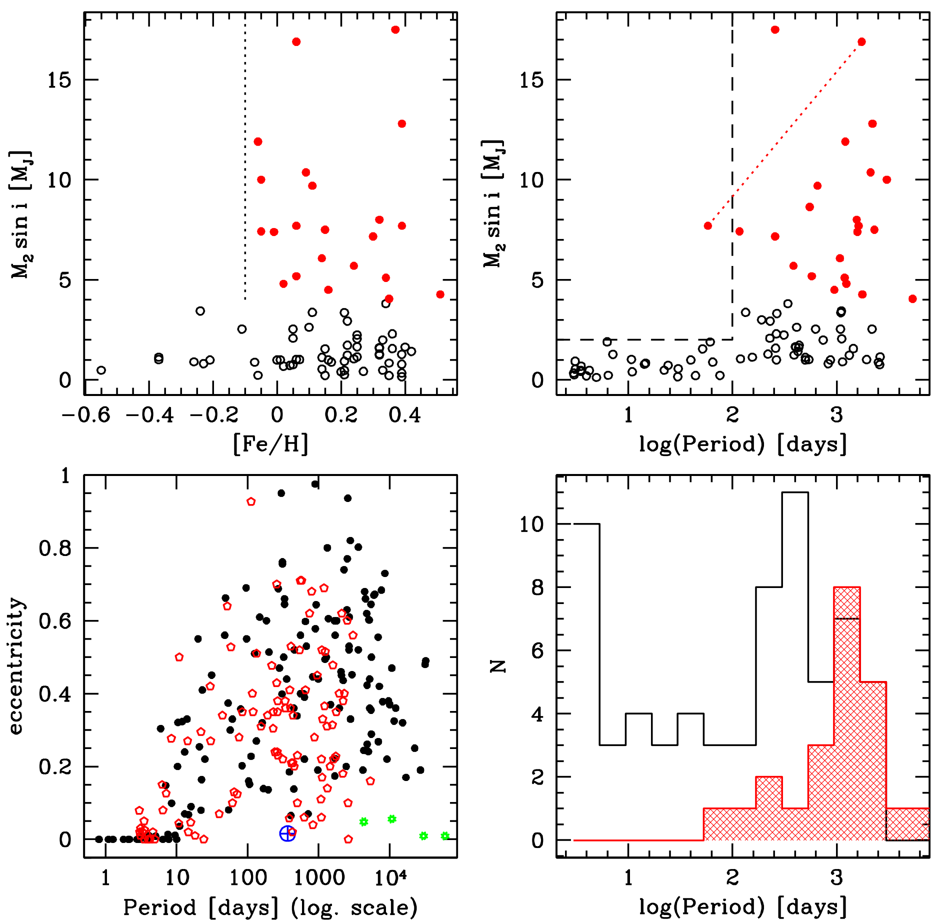

Figure 3. Planetary parameter distributions. Diagrams on the left are for all planets whereas planets orbiting stellar binary components are removed in the right panels. In the upper diagrams, the symbol coding represents two different mass regimes (limit at $4\,M_{Jup}$). The same splitting is used for the histograms in the lower right pannel. In the lower left diagram, filled circles are for G-K-M binaries and open pentagons for extrasolar planets

The period distribution: a valley at intermediate periods. Another very interesting feature is observed in the period distribution: a shortage of planets with periods between roughly 30 and 100 days (Figure 3, lower right). The peak at short period is probably formed by the pile-up of migrating lower-mass planets, stopped close to the central star. The rise of the distribution at longer periods is due to the increase of the time base of the RV surveys unveiling more and more massive candidates that form and stay further out (see discussion in Udry et al. 2002b). The observed valley in the period distribution can then just be seen as a transition region between two planet categories which suffered different migration behaviors.

The $(e, \log P)$ *diagram.* The similarity between the $(e, \log P)$ distributions of binaries and planetary systems is striking. Although some differences appear at short periods – a few non-circular planetary orbits with $P \leq 10\,\mathrm{d}$ or circular orbits with $P \geq 10\,\mathrm{d}$ – the likeness between the 2 distributions is largely unexplained. However, with longer period planets being detected, a population of circular planets clearly differentiate themselves from the stellar binary population (Figure 3, lower left). They resemble more the giant planets in our solar system.

4. Detection Black Sheep and Complex Systems

The mentioned statistical emerging features of the orbital element distributions and stellar properties are only useful if the planet sample is cleaned of "bad" candidates. Several announced candidates are presently put into question. It is thus very important to discuss them in more detail, and decide whether we can keep them or must reject them from the planet list. In addition to stellar pulsation inducing a periodic motion of the photosphere, further causes of false planet detections may be pointed out. Specific diagnostics have to be defined to tackle this problem. Some cases are discussed in the following subsections.

Activity effect for HD *192263?* Activity-induced spots on the surface of the star change the shape of the spectral lines and thus induce periodic RV variations over a few stellar rotation periods. A seminal example of this effect is provided by HD 166435 (Queloz et al. 2001b). In that case, in-phase varying photometric, activity-index and bisector shape measurements provide safe diagnostics for the intrinsic origin of the RV variation. Another case was recently proposed by Henry et al. (2002) that measured a photometric variation of the planet-hosting star HD 192263, on time scales compatible with the orbital period. In this case, although we confirm the photometric variation, the line bisector is not varying and the phase of the orbital motion is conserved since several years, at a much better level than for HD 166435. Moreover, recent simultaneous measurements show that the photometric variation is erratic whereas the RV points continue to follow precisely the Keplerian curve (Santos et al., in preparation).

The HD 41004 and HD 223084 triple systems. In the case of close visual or spectroscopic binaries, the periodic contamination of a second faint binary spectrum in triple systems also mimics small RV variations of the primary. Two examples are already known: HD 41004 completely solved in Santos et al. (2002b) and Zucker et al. (2002), and HD 223084 (Eggenberger et al. 2003).

The disappearance of HD 83443 c? Another example of a planetary candidate put into question is the second planet orbiting HD 83443. The clear RV signal detected 2 years ago (Mayor et al. 2000) – not appearing on contemporarily observed constant stars – has now disappeared in more recent observations and in recent Keck data (Butler et al. 2002b). The transient observed signal could be attributed to activity as the corresponding period ($\sim 29\,\mathrm{d}$) is compatible with the stellar rotation, but again no clear indication of line shape variation came out of the data. Also, if several planets are actually orbiting the star, their global influence may induce complex features in the RV curve.

These cases show how careful we have to be before drawing strong conclusions about acceptance or rejection of new planet candidates. Experience has shown that in both directions mistakes were made. In all cases, the whole range of available diagnostics have to be applied. For HD 192263 b and HD 83443 c, the safest statement that can be made at this point is that further investigations are needed before convincingly rejecting them as planetary candidates.

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